LOW BTU GASIFICATION: AN ANNOTATED BIBLIOGRAPHY OF THE TECHNOLOGY

A Report to the Montana Energy Advisory Council

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Preface

This report consists of an annotated bibliography of recent literature related to low BTU gasification. It is not all encompassing but it does give an indication of the scope and content of the extant literature. All of the information contained in this report was abstracted directly from the cited literature and no particular effort was made to paraphrase the contents of the annotated citations. This report is designed to be a guide for the interested researcher who wishes to further pursue the technology of low BTU gasification. No attempt was made to synthesize or critically review the contents of the articles; however, the annotations do reflect the interests of the author and the interested reader should review the original article for further information and technical details.

Hammond, Ogden H. and Robert Baron. "Synthetic Fuels: Prices, Prospects, and Prior Art", American Scientist, July-August 1976, pp. 407-417.

The costs of synthetic fuels processed are correlated with the increase in the net hydrogen to carbon (H/C) ratio required to convert the raw input hydrocarbon to the synthetic product. The net H/C ratio excludes hydrogen bound to oxygen and sulfur in the form H_2O and H_2S. The lower the net H/C ratio of the starting material and the higher the net H/C ratio of the desired product, the more capital equipment will be required; however, relatively expensive raw materials with high net H/C ratios may be substituted for this capital equipment.

Hydrocarbon	Net H/C Ratio	Sulfur/Carbon Atomic Ratio	Nitrogen/Carbon Atomic Ratio
Methane	4.	0.	0.
Gasoline $(CH_2)_N$	2.	0.	0.
Colorado Oil Shale	1.58	.019	.028
Athabasca Tar Sands	1.50	.019	.004
Bituminous Coal	0.6	.016	.018
Subbituminous Coal	0.5	.007	.016
Lignite	0.25	.005	.015

Only part of the enormous increase in the cost of synthetic fuel plants is due to inflation. A significant fraction of the increase is the result of oversights which could not be discovered until actual commercial designs were made. As a general rule, real costs of new and improved processes tend to double as soon as an attempt is made to construct them.

The costs of synthetic fuel plants are extremely sensitive to the cost of capital equipment and the rate of return on investment. The costs of synthetic fuels are also extremely dependent on the stream factor (amount of actual annual output/designed annual output assuming continuous operation). Oil refineries have a top stream factor of about 0.91. Synthetic fuel economics generally assume a similar stream factor. A 0.5 stream factor will increase synthetic fuel costs by 100 percent.

Feretti, Emmett J. "Technology and Economics of Industrial Fuel Gas from Coal", Presented at the American Chemical Society Centennial Meeting, New York, N.Y., April 1976.

There are several types of low BTU gasifiers:

(1) Fixed or Stirred Bed Gasifiers: These gasifiers were used in the United States up through the 1940's. They were generally operated at atmospheric pressure, air blown, and used non-caking coals, coke or anthracite. The productivity of these gasifiers ranged from 0.5 through 1.5 × 10^9 BTU per day. Caking coals hamper the operation of fixed bed gasifers

and thus require special stirrers or high steam injection rates. Stirred or fixed bed gasifiers generally produce significant amounts of tars and phenols which require additional processing. The technology of fixed bed or stirred bed gasification is well developed and their performance is predictable.

(2) Fluid Bed Gasifiers: These gasifiers were first built in Germany and are designed to be used with non-caking coals. Fluid bed gasification generally requires an added pretreatment step or char recirculation to utilize caking coals. Phenols are also produced in some cases.

(3) Suspension Fired Gasifiers: Suspension fired gasifiers can utilize all types of coal and produce no tars or phenols; but, they require that the feed coal be pulverized to approximately 200 mesh size. Considerable experience exists with European designed suspension-fired gasifiers.

It should be noted that the specific characteristics of the coal feedstock will have a profound effect on the performance of the gasifier. Also make up water requirements for a typical industrial low BTU gasification plant can be as high as 750 gallons per minute for every 1,000 tons per day of coal feed.

In mid-1975 dollars, 60 percent of the cost of a typical industrial low BTU gas plant is in equipment and materials. Twenty percent of the total plant investment is required for environmental protection facilities. The method of financing is very important in determining the cost of the gas produced. The cost of the coal feedstock is another major factor in the cost of the product gas. Also economics of scale are evident as there is a substantial drop in gas costs as the plant size increases. The higher cost of gas produced by smaller plants is due to redundancy to insure availability.

For low BTU gasification plants in the size range of 20 through 75 X 10^9 BTU per day, the 20-year average gas cost can range from over $\$4/10^6$ BTU to slightly under $\$3/10^6$ BTU with utility financing and coal at $20 per ton.

Following are Figures 1-6 which describe the economics and operating characteristics of low BTU gasifiers.

FIGURE 1

COMPARISON OF FUEL GASES

	Heating Value	Flame Temp. °F	Volumes @ 15% Excess Air scf/MM Btu		
			Fuel	Air	Flue Gas
Low-Btu Gas	153	2,853	7,043	9,860	15,790
Industrial Fuel Gas	298	3,767	3,584	8,900	11,260
Coke Oven Gas	570	3,452	1,961	11,140	12,600
Natural Gas	970	3,279	1,145	12,340	13,480

SOURCE: Feretti, Emmett J. "Technology and Economics of Industrial Fuel Gas from Coal", Presented at the American Chemical Society Centennial Meeting, New York, NY, April, 1976.

FIGURE 2

GASIFIER PRODUCTIVITY AND RESPONSE CHARACTERISTICS

GASIFIER PRODUCTIVITY

	COAL FEED TONS/DAY
EARLY TYPES: ATM, AIR	30 - 130
FIXED BED, 400 PSIG, O_2, NON-CAKING	900
FIXED BED, 400 PSIG, AIR, NON-CAKING	600
STIRRED BED, 400 PSIG, O_2, CAKING	500
FLUID BED, NON-CAKING, SINGLE-STAGE	1,000
SUSPENSION FIRED, (ELLIPSOID) 2-HEAD, ATM., O_2	400
4-HEAD, ATM., O_2 (NEW)	850
SUSPENSION FIRED, (CYLINDRICAL) O_2, ATM (EARLIER OPERATION)	400
O_2, 50 PSIG (NEW DESIGN POTENTIAL)	1,000
O_2, 175 PSIG (NEW DESIGN POTENTIAL)	3,000
AIR, 50 PSIG (NEW DESIGN POTENTIAL)	500

GASIFIER RESPONSE CHARACTERISTICS

GASIFIER TYPE	TURNDOWN RATIO	TIME TO ACHIEVE FULL RATE FROM START: START	MINUTES
Fixed Bed	100/25	50%	12
Fluid Bed	100/25	50%	< 5
Suspension-Fired, ATM	100/60 (1)	60%	<10
Suspension-Fired, 50 PSIG	100/25 (2)	50%	<10

(1) because of limitations in the burners and feeder systems.

(2) broader because of multiplicity of burners.

SOURCE: Feretti, Emmett J. "Technology and Economics of Industrial Fuel Gas from Coal", Presented at the American Chemical Society Centennial Meeting, New York, NY, April, 1976.

FIGURE 3

COAL GASIFICATION COST

GAS PRODUCTION: 50 x 10^9 BTU/DAY

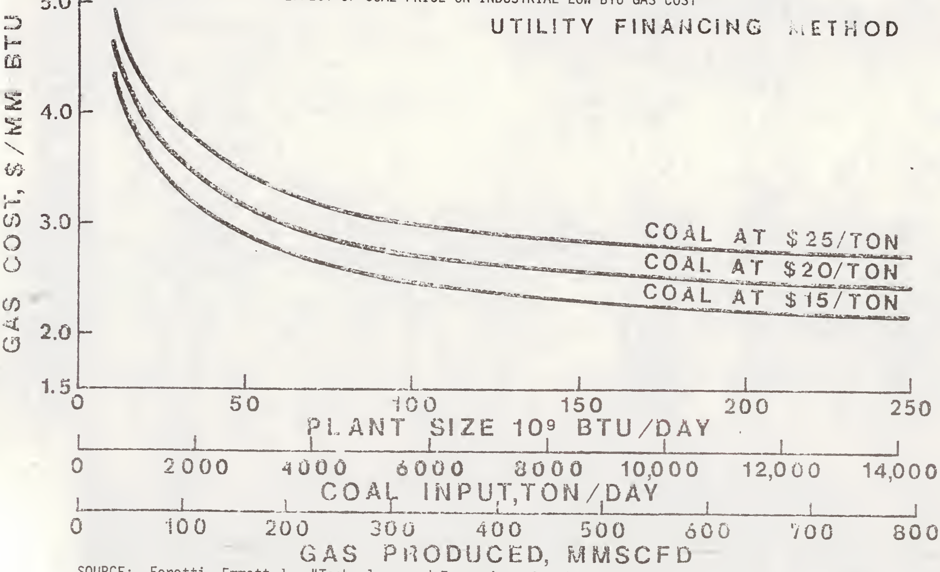
COAL COST: $20/TON

	UTILITY FINANCING DRAVO BASIS	DISCOUNTED CASH FLOW DRAVO BASIS	DISCOUNTED CASH FLOW ACS BASIS
PLANT INVESTMENT: $MM			
Coal Handling & Gasification	74.9	74.9	74.9
Purification, Sulfur Recovery, Waste Water Treatment, & Ash Disposal	30.0	30.0	30.0
Offsites (Utilities, Site Preparation, O_2 Plant)	51.6	51.6	51.6
TOTAL PLANT INVESTMENT	156.5	156.5	156.5
Depreciable Assets (1)	188.0	188.0	187.0
TOTAL CAPITAL REQUIREMENT (2)	193.5	193.5	192.8
PLANT OPERATING EXPENSE, $MM/Yr.			
Raw Material & Chemicals	19.2	19.2	19.2
Purchased Utilities (3)	2.1	2.1	1.6
Direct Operating Labor	.7	.7	.8
Maintenance Labor (4)	.6	.6	3.1
Supervision, Admin.& Overhead (5)	1.6	1.5	3.8
Supplies (6)	.8	.8	3.1
TOTAL, $MM/Yr.	25.0	25.0	31.6
By-Product Credits	(1.0)	(1.0)	(1.0)
Insurance & Local Taxes	3.1	3.1	3.1
Operating Expense w/o Depreciation	27.1	27.1	33.7
Depreciation	9.4	9.4	9.4
Pretax Income Plus Interest	14.9	25.3	26.6
TOTAL REVENUE REQUIREMENT, $MM/Yr	51.4	61.8	69.7
AVERAGE GAS COST, $MM/BTU	3.13	3.76	4.24
DCF INTEREST RATE OF RETURN	--	10%	10%
RETURN ON EQUITY	15%	--	--
RETURN ON DEBT	9%	--	--
DEBT/EQUITY RATIO	70:30	0:100	0:100

SOURCE: Feretti, Emmett J. "Technology and Economics of Industrial Fuel Gas from Coal", Presented at the American Chemical Society Centennial Meeting, New York, NY, April, 1976.

FIGURE 4

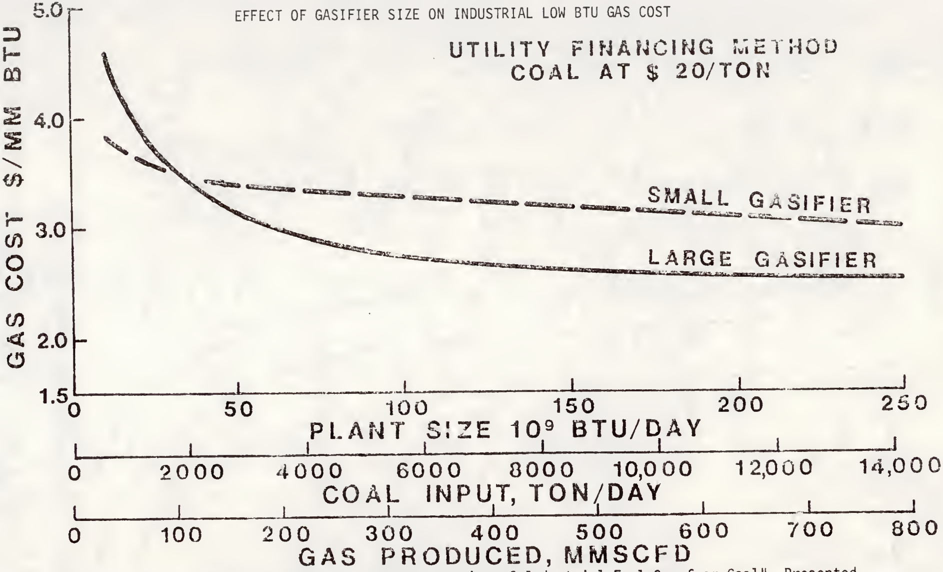
EFFECT OF COAL PRICE ON INDUSTRIAL LOW BTU GAS COST



SOURCE: Feretti, Emmett J. "Technology and Economics of Industrial Fuel Gas from Coal", Presented at the American Chemical Society Centennial Meeting, New York, NY, April, 1976.

FIGURE 5

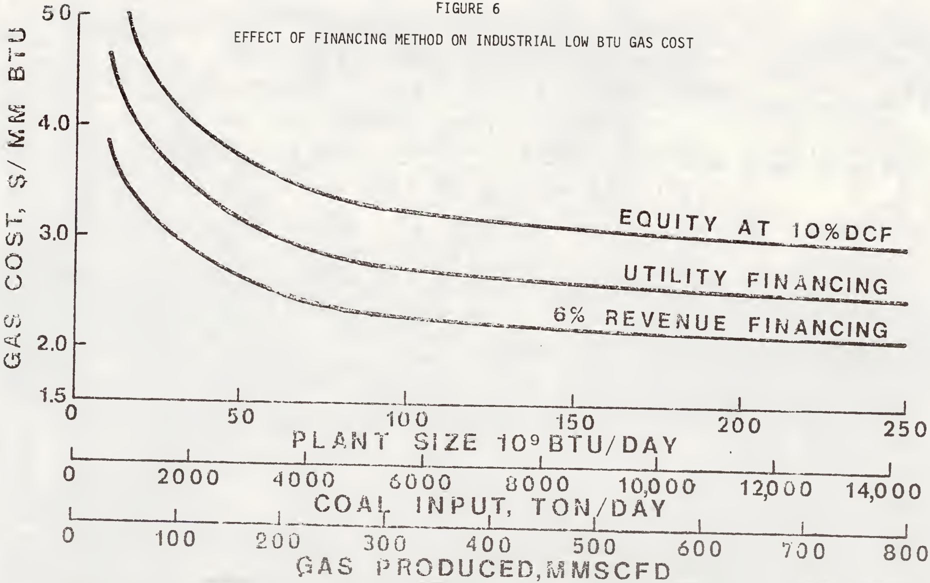
EFFECT OF GASIFIER SIZE ON INDUSTRIAL LOW BTU GAS COST



SOURCE: Feretti, Emmett J. "Technology and Economics of Industrial Fuel Gas from Coal", Presented at the American Chemical Society Centennial Meeting, New York, NY, April, 1976.

FIGURE 6

EFFECT OF FINANCING METHOD ON INDUSTRIAL LOW BTU GAS COST



SOURCE: Feretti, Emmett J. "Technology and Economics of Industrial Fuel Gas from Coal", Presented at the American Chemical Society Centennial Meeting, New York, NY, April, 1976

Tillman, David A. "Status of Coal Gasification", Environmental Science and Technology, Vol. 10, No. 1, January 1976, pp. 34-38.

There are two major factors which provide economic limitations to coal gasification technology. These are the efficiency of conversion of coal to gas and the water consumption of the conversion process.

The market characteristics of low BTU gas and pipeline quality synthetic natural gas differ significantly. Low BTU gas is not transportable over long distances. Also, users of low BTU gas must change their burner ports and gas feed apparatus. Finally, industrial users will tend to size their gasification plants to their own specific requirements rather than build the largest unit possible for optimized economies of scale.

Following are descriptions of various low BTU gasification technologies:

Wellman-Galusha: This technology is currently being used by the Glen-Gery Corporation of Shoemaker, Pennsylvania, to supply gas for the manufacture of bricks. The Wellman-Galusha gasifier is currently produced by McDowell-Wellman Engineering and has a maximum capacity of 85 tons of coal feed per day.

In the Wellman-Galusha gasification process, coal is fed into the top of a vertical reactor. The input coal is first dried, then pyrolyzed as it proceeds downward. The coal finally reaches the combustion zone where it is fired with minimal quantities of air. Hot gases rise upward through a countercurrent flow of solid coal. The thermal efficiency of the process is high; however, large volumes of tars are produced. The

Wellman-Galusha gasifier operates at atmospheric pressure and can utilize caking coals through the use of a stirring device. The reactor produces gas of 150 to 170 BTU/scf with a composition of 2.7 percent methane, 28.6 percent carbon monoxide, 15 percent hydrogen, 3.4 percent carbon dioxide and 50.3 percent nitrogen.

Koppers-Totzek: The Koppers Totzek gasifier is a suspension type reactor operating at atmospheric pressure. It has an input coal feed rate of 450 to 850 tons per day and will operate with all types of dried pulverized coal. Pulverized coal, oxygen, and steam are all fed into the gasification chamber where the conversion reactions occur almost simultaneously. The Koppers-Totzek gasifier produces gas with a heating value of 290 to 300 BTU/scf and a chemical composition of 55.9 percent carbon monoxide, 35.4 percent hydrogen, 7.2 percent carbon dioxide, 1.1 percent nitrogen and 0.3 percent hydrogen sulfide. There are 17 Koppers-Totzek gasifiers operating around the world.

Lurgi: The Lurgi gasifier is a modified fixed bed pressurized reactor which can operate using either oxygen or air. The Lurgi gasifier has traditionally been operated with non-caking coals; however, caking coals have recently been successfully gasified at Westfield, Scotland.

In the Lurgi process, sized coal is fed into a lock hopper at the top of the reactor vessel while steam and oxygen are fed in through the bottom of the reaction chamber. Reactors may process as much as 950 tons of input coal per day. The air-fed Lurgi gasifier produces gas with a heating value of 110 to 180 BTU/scf with a chemical composition of three percent methane, 11 percent carbon monoxide, 17 percent hydrogen, 11 percent carbon dioxide, 31 percent nitrogen, 26 percent water, and 0.5 percent hydrogen sulfide. Oxygen blown systems produce 500 BTU/scf gas with ten percent methane.

Gasifier Efficiencies: The thermal efficiency of the Wellman-Galusha gasifier for industrial use,including sensible heat and the heating value of the tars and volatiles produced is 92 percent. The Glen-Gery gasifier operates at 90 percent thermal efficiency using anthracite. The cold, clean gas efficiency of the Wellman-Galusha gasifier is 75 percent.

The thermal efficiency of the Koppers-Totzek reactor ranges from 85 to 90 percent with a cold, clean gas efficiency of 74 to 75 percent. Finally, the Lurgi reactor operates at a thermal efficiency of 80 percent with a cold, clean gas efficiency of 70 percent; however, the Lurgi produces pressurized gas which can be converted to mechanical energy to increase the overall efficiency of the process.

U.S. Energy Research and Development Administration. Energy From Coal, Prepared for the Office of Fossil Energy, United States Research and Development Administration under Contract No. E (49-18)-2225 by Tetra Tech, Inc., ERDA 76-67, Washington, D.C.: Government Printing Office, 1976.

There are three generalized types of low BTU gasifiers: fixed bed, fluidized bed, and entrained flow.

The difference in the design of individual gasifier reactors can be best characterized by the magnitude and direction of movement of the coal particles. In a fixed bed reactor, the gas velocity is relatively low and the solid particles remain stationary. If the gas velocity is increased, the drag forces on the particles will equal the gravitational forces on the particles. At this point, the bed expands and the distance between the particles becomes significantly greater. The particles also require a rapid random velocity throughout the reactor which makes the reactor appear like a container of rapidly boiling liquid and for this reason is referred to as being fluidized. Because the particles are in such violent motion and mix in all directions, such a reactor is frequently referred to as a stirred reactor. If the gas velocity into the reactor is increased to even higher values, then the interface between the bed and the gas above it disappears. The distance between the particles increases significantly and the particles experience practically no interaction. This condition is referred to as entrained flow because the particles are merely swept along by the high velocity gas stream.

Anderson, T.D., et al. An Assessment of Industrial Energy Options Based on Coal and Nuclear Systems. Oak Ridge Tennessee: Oak Ridge National Laboratory, ORNL-4995, July 1975.

There are four principal processes for producing low BTU gas. The Lurgi process is offered by the American Lurgi Company, New York, N.Y.; the Koppers-Totzek process is offered by the Koppers Company, Pittsburg, Pennsylvania; the Wellman-Galusha process is offered by the McDowell-Wellman Company, Cleveland, Ohio; and the Winkler process is offered by Davy

Power Gas Incorporated, Lakelard, Florida.

Winkler Process: In the Winkler process, crushed, dried coal is transferred from fuel bunkers to gas generators with variable speed screws. A fluidized bed of coal particles is maintained in the gasifier by the high velocity gas stream of steam and oxygen flowing up from the bottom of the generator. All tars and heavy hydrocarbons are reacted to form product gas. As a result of fluidization, the process ash particles are segregated according to size and density; the heavier particles fall down through the fluidized bed and pass into the ash discharge unit at the bottom of the generator, while the lighter particles are carried up out of the bed by the product gas to be further gasified in the space above the bed. The manufacturer claims great flexibility in capacity with shutdown occuring in minutes.

Economic Analysis: The major items in the cost of gas production are coal, capital, labor, electricity, water, and maintenance. If oxygen is used, that cost is also significant. Oxygen requirements vary among the commercially available gasifiers; however, the oxygen requirements represents 50 percent of the raw material cost for the Lurgi process and 60 percent for the Koppers-Totzek suspension gasifier.

Figure 7 indicates various processes for the production of Low BTU gas from coal, while Figure 8 gives the authors' gas cost estimates in 1975 dollars.

FIGURE 7

PROCESSES FOR THE PRODUCTION OF LOW AND INTERMEDIATE BTU GAS FROM COAL

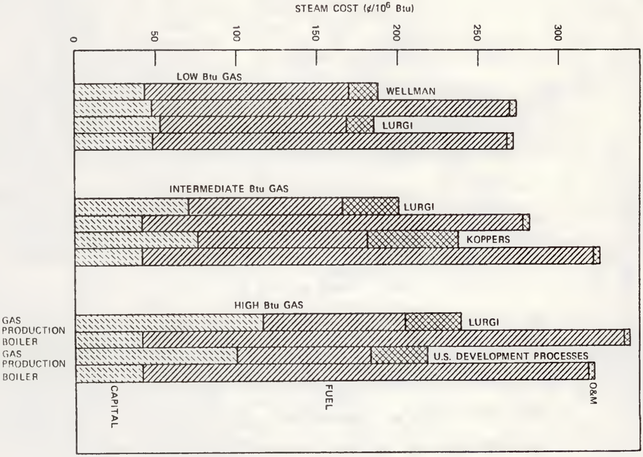
Process	Gasifier type	Gasifier pressure (psig)	Oxidizing medium	Comments
Lurgi	Downward moving stirred bed, nonslagging	300–450	Air or oxygen	Process is in commercial operation on sized, noncaking coal; plans are under way to test operation on caking bituminous coal
Koppers-Totzek	Concurrent solid-gas combustion, slagging	1–5	Oxygen or oxygen-enriched air	Process is in commercial operation using oxygen; offered in sizes to 35 tons of coal per hour; tests are planned using enriched air; can handle any type of coal
Wellman-Galusha	Downward moving stirred bed, nonslagging	1–300	Air or oxygen	Process is in commercial operation using coke or noncaking coals, mostly in the steel and ceramics industries; offered in sizes to 7000 lb per hour of bituminous coal; Bureau of Mines has a pilot plant operating on caking coal at pressures up to 125 psig, capacity about 20 tons/day; tests are planned at 300 psig to increase throughput
Winkler	Fluidized bed	15	Air or oxygen	Sixteen installations were built outside the U.S. from 1926 to 1960 with generator capacities of 100–300 × 10^6 Btu/hr; three installations are presently in operation; process description states it will operate on all coals; tests are planned at 15 atm

Gasifier type	Oxygen required (lb O/lb fuel)
Lurgi	0.37
Winkler	0.49
Koppers-Totzek	0.80

SOURCE: Anderson T. D. et al. An Assessment of Industrial Energy Options based on Coal and Nuclear Systems. Oak Ridge, Tennessee: Oak Ridge National Laboratory, ORNL-4995, July, 1975.

FIGURE 8

COST OF STEAM FROM A GAS FIRED BOILER



SOURCE: Anderson T. D. et al. An Assessment of Industrial Energy Options Based on Coal and Nuclear Systems. Oak Ridge, Tennessee: Oak Ridge National Laboratory, ORNL-4995, July , 1975

Dravo Corporation. Handbook of Gasifiers and Gas Treatment Systems, Pittsburg, Pennsylvania: Dravo Corporation, February 1976. Prepared for U.S. Energy Research and Development Administration under Contract No. E (49-18) 1772.

Following are technical descriptions of various low BTU gasifiers.

Babcock and Wilcox

TYPE: Entrained flow slagging gasifier.

STATE OF DEVELOPMENT: Demonstrated on a pilot plant and semi-commercial scale in the 1950's and 1960's, largest plant -- 400 tons per day.

DESCRIPTION: The reactor is of vertical cylindrical construction with an outer pressure shell and an inner shell of tube wall construction covered with castable refractory in the reaction zone. Dried, pulverized coal and oxygen are fed into the coal burners of the reactor. Combustion reactions take place in the lower section of the reaction zone at approximately 3,400 degrees Fahrenheit. Sprayed water is used for temperature control. Ash in coal forms molten slag which is continuously withdrawn into a quench tank. The combustion gases are cooled by the water-gas reaction in the upper section of the reaction zone to a temperature of 1,800 degrees Fahrenheit before leaving the gasifier. On the first pass, 85 percent of the carbon is gasified and the char is recovered by cyclones and regasified.

FEED REQUIREMENTS: Pulverized coal 70 to 90 percent through 200 mesh, accepts all types of coal. Optimum performance is obtained when the ash initial deformation and ash fluid temperatures are close and in the range of 1,900 to 2,400 degrees Fahrenheit.

OPERATING CONDITIONS: The reactor operates at 3,400 degrees Fahrenheit at atmospheric to 300 psig. pressure.

GAS PRODUCED:

Feed Coal	O_2 Blown Pittsburgh #8 13,860 BTU/scf	Air Blown Pittsburgh #8 13,860 BTU/scf
Mole % CO	65.3	23.3
CO_2	5.0	4.6
H_2	27.9	8.4
H_2S + COS	0.6	0.2
N_2 + Ar	1.2	63.5
HHV BTU/scf Dry	301	102

BY-PRODUCTS: The major by-product is 4,300 pounds of steam per ton of coal consumed at 600 psig. No oils or tars are produced.

THERMAL EFFICIENCY: The cooled, clean gas efficiency of the oxygen blown process is 74 percent. The overall thermal efficiency of the process is 68 percent.

Koppers-Totzek

TYPE: Entrained flow slagging gasifier.

STATE OF DEVELOPMENT: The Koppers-Totzek (K-T) process is a commercially proven low pressure process for producing synthetic gas from solid or liquid carbonaceous feeds.

DESCRIPTION: The two headed KT gasifier is horizontal and ellipsoidal in shape, with two heads shaped as truncated cones mounted on the ends. A waste heat boiler is mounted on the top to recover heat from the hot effluent gases. Coal, oxygen and steam are injected through the combustion heads. Coal is dried, pulverized to 70 percent to 90 percent through 200 mesh, fed by a screw feeder to a mixing nozzle where it is mixed with steam and oxygen. Coal is oxidized in the gasifier, producing a temperature in the flame zone of about 3,500 degrees Fahrenheit. The ash is liquified and 50 percent flows down the gasifier walls and drains into a slag quench tank. The remainder of the ash leaves the gasifier as fine slag particles entrained in the exit gas. Gas leaving the waste heat boiler is water scrubbed and cooled in a washer cooler and Theisen disintegrator system to eliminate particulate. The scrubbed cooled gas is then processed in a sulfur removal system, resulting in the medium BTU product gas.

FEED REQUIREMENTS: Pulverized coal, about 70 to 90 percent through 200 mesh, will accept all types of coal. The moisture content of coal can limit operation by affecting pulverized coal flow. The gasifier handles a wide range of ash fusion temperatures.

OPERATING CONDITIONS: The gasifier combustion zone temperature is 3,500 degrees Fahrenheit at a slight positive pressure.

GAS PRODUCED:

Input Coal 1,2640 BTU/lb. Eastern Coal

Mole %	CO	52.5
	CO_2	10
	H_2	36
	H_2S + COS	.4
	N_2 + Ar	1.1
	HHV BTU/scf Dry	286

THERMAL EFFICIENCY: Cold gas efficiency 75 percent, overall efficiency 68 percent.

Winkler Fluid Bed Gasifier

TYPE: Fluid bed gasifier.

STATE OF DEVELOPMENT: The Winkler process is a commercially proven process for manufacturing synthetic gas from coal.

DESCRIPTION: The Winkler gasifier has a vertical cylindrical construction with a steel shell lined on the inside with refractory. The coal feed inlet is located in the lower portion of the gasifier. Steam and oxygen are charged through nozzles located at several levels in the fluid bed. Crushed (0 x 3/8") coal is fed to the gasifier by variable speed screws. Steam, oxygen, (air), and coal particles form a fluidized bed forming H_2, CO, CO_2 and CH_4. Uniform temperature is quickly reached as is equilibrium. All of the tars and heavy oils are gasified. The residual ash particles are segregated in the fluidized bed according to size and specific gravity. Heavy particulate drops and passes into an ash discharge unit at the bottom of the gasifier; light particles are carried through the bed with the product gas. Maximum temperature in the gasifier occurs above the fluidized bed and ash particles can melt here so a radiant heat boiler inside the gasifier is required. Ash is removed from the gas stream in the waste heat boiler and in cyclones. Residual ash is removed in wet scrubbers.

FEED REQUIREMENTS: Crushed 0 x 3/8" coal -- used mainly with lignite and subbituminous coals. Bituminous coals with a free swelling index less than four may be acceptable. The limit on moisture content is estimated at 25 to 30 percent for lignite and less for less reactive (higher grade) coals.

OPERATING CONDITIONS: The gasifier operates at 1,500 to 1,800 degrees Fahrenheit at atmospheric pressure.

GAS PRODUCED:

Feed Coal		O_2 Blown Lignite	Air Blown Western Subbituminous
HHV Input Coal		10,200	10,200
Mole %	CO	48.2	22
	CO_2	13.8	7
	H_2	35.3	14
	CH_4	1.8	1
	N_2 + Ar	0.9	56
	HHV BTU/scf Dry	288	126

THERMAL EFFICIENCY: Cold gas efficiency 72 percent, overall thermal efficiency 69 percent.

Lurgi

TYPE: Fixed-bed gasifier.

STATE OF DEVELOPMENT: The Lurgi process is a commercially proven high pressure process for manufacturing fuel gas and other by-products from coal.

DESCRIPTION: The Lurgi gasifier is a fixed bed type gasifier with a vertical cylindrical construction. It is a high pressure gasifier operating at 350 to 450 psig. The main gasifier shell is surrounded by a water jacket through which boiler feed water is circulated for waste heat recovery. A lock hopper feeds the input coal into the top of the gasifier. A motor driven grate is used to withdraw the ash formed. Coal is screened to obtain 1/8" x 1 1/2" coal. Fines are removed. Steam and oxygen are introduced into the bottom of the gasifier through the rotating ash grate. As the steam and oxygen pass upward, four different zones can be characterized. They are from bottom to top: carbon combustion, gasification, devolatilization, and drying. Crude gas formed in the gasifier leaves from the top and flows through a scrubber cooler. The gas then passes through a waste heat boiler where it is cooled and low pressure steam generated. Condensate formed is cooled and sent to a tar/liquor separator. Gas exiting through the waste heat boiler is further cooled by three water cooled heat exchangers in series. A part of the condensate recovered from this cooling is sent to the tar/liquor separator, and the remainder is sent to an oil/liquor separator. After decantation the tar/liquor and oil/liquor are fed to a phenosolvan unit and an ammonia plat where crude phenols and ammonia are recovered. Gas from the final cooler is desulfurized in an acid gas removal unit.

FEED REQUIREMENTS: Sized coal 1/8" x 1 1/2". Gasifier will accept caking and non-caking coals. Montana Rosebud and North Dakota lignite have been gasified in the Lurgi. Caking coals slightly reduces the gasifier throughput and increases the steam requirement. The initial deformation temperature of the ash should not be significantly lower than the combustion zone temperature in order to avoid clinker formation.

OPERATING CONDITIONS: Temperature in combustion zone -- 1,800 to 2,500 degrees Fahrenheit, temperature in gasification zone 1,200 to 1,500 degrees Fahrenheit, temperature of gas leaving the gasifier 700 to 1,000 degrees Fahrenheit, pressure 350 to 450 psig. operating temperatures depend on the type of coal gasified.

BY PRODUCTS: Tar 75 lb./ton of coal. Tar/oil 25 lb./ton. Oil/liquor + tar/liquor 5,200 lb./ton. Steam at 350 psig. 1,300 lb./ton. Steam at 100 psig. 3,530 lb./ton.

GAS PRODUCED:

		O_2 Blown Operation
HHV Input Coal		14,900 BTU/lb. Dry
Mole %	CO	16.9
	CO_2	31.5
	H_2	39.4
	CH_4	9
	C_2H_6	0.7
	C_2H_4	0.1
	H_2S + COS	0.8
	N_2 + Ar	1.6
	HHV BTU/scf Dry	288

THERMAL EFFICIENCY: Cold gas efficiency -- 63 percent; overall thermal efficiency -- 76 percent.

Wellman-Galusha

TYPE: Fixed bed gasifier with or without central agitator.

STATE OF DEVELOPMENT: The Wellman-Galusha process has been commercial for more than 35 years. Over 150 Wellman-Galusha gasifiers have been installed worldwide for various industrial applications.

DESCRIPTION: There are two types of gasifiers -- standard and agitated. The agitated gasifier has a rated capacity 25 percent higher and can handle volatile caking bituminous coals. Following is a description of the agitated gasifier.

The gasifier itself is water jacketed. Water in the jacket completely surrounds the gasifier and also covers the top. The agitator has a revolving horizontal arm which also spirals vertically below the surface of the coal bed to retard channeling and maintain a uniform fuel bed. A revolving step type grate is mounted eccentrically at the bottom of the gasifier on a center post. It distributes the air-stream blast into the coal bed and forces the ash formed into the ash bin. Crushed coal is fed into the coal bin, and it flows into the feeding compartment and hence through vertical feed pipes. A fan supplies the air required for gasification. The air is passed over the top of the water in the jacket, picking up steam required for the blast. Saturation of the blast is regulated by adjusting the jacket water temperature, normally between 150 to 180 degrees Fahrenheit. Air-steam blast passes upward through the ash, combustion, and gasification zones. Combustion and gasification reactions occur, resulting in a gas containing mainly CO, CO_2, H_2, and N_2. The hot gas produced dries and preheats the incoming coal, and then leaves the gasifier. Gas leaving the gasifier is passed through a cyclone, where the heavy dust (ash and char) particles are removed. The gas leaving the cyclone can be used hot if its sulfur content is acceptable. Otherwise it can be scrubbed and cooled in a direct contact counter current water cooler, and then sent for sulfur removal. If the gas contains tar, it may be separated from the cooled gas by mechanical or electrical precipitation methods.

FEED REQUIREMENTS: Crushed coal +5/16" to 9/16" preferred for anthracite; +1" to 2" preferred for bituminous. Larger particle size can be used for the more reactive bituminous coal. There is no apparent limit on the free swelling index of coals that can be gasified in the agitated gasifier. Coal ash softening points higher than 2,200 degrees Fahrenheit are preferred; softening points down to about 1,800 degrees Fahrenheit can be handled by introducing more steam.

OPERATING CONDITIONS: Temperature in combustion zone -- 2,400 degrees Fahrenheit; temperature of gas leaving the gasifier -- 800 to 1,000 degrees Fahrenheit (anthracite), 1,100 to 1,200 degrees Fahrenheit (bituminous); pressure = near atmospheric.

GAS PRODUCED:

Steam-Air Blown Operation

Feed Coal		Bituminous	Anthracite
HHV BTU/lb.		14,000	13,500
Mole %	CO	28.6	27.1
	CO_2	3.4	5.0
	H_2	15.0	16.6
	CH_4	2.7	0.5
	N_2	50.3	50.9
	Tar (lb./ft.^{3})	00.1	--
	HHV BTU/scf Dry	168	146

BY PRODUCTS: Tar is produced from bituminous coals at a rate of approximately 120 lb./ton.

Woodall-Duckhan Gas Intergrale

TYPE: Fixed bed gasifier.

STATE OF DEVELOPMENT: This two-stage gasification process has been in operation for 30 years producing industrial fuel gases.

DESCRIPTION: The gasifier is of vertical cylindrical construction with a rotating grate in the bottom of the reactor. It distributes the incoming air and steam while removing the ash. The gasifier contains three zones: a lower gasification zone which is water-jacketed to provide temperature control, a refractory lined distillation zone, and a refractory lined drying zone. Sized coal is mechanically transported from a storage hopper to a surge hopper located above the gasifier. It then enters the gasifier via a lock hopper system and coal distributor. After leaving the distributor, the coal first loses its water content in the drying zone in the upper portion of the unit on contact with hot gas (250 degrees Fahrenheit) generated in the gasification zone. The coal then descends through a higher temperature distillation zone, where the volatile matter distills off into the ascending gas stream. If the coal is a caking coal, it will partially fluidize in the distillation zone and resolidify to form semi-coke. Non-caking coals produce a char. This material is further heated by the hot, rising gas until it reaches the gasification zone. In the gasification zone, it is contacted counter-currently with steam and oxygen (or air) in an unagitated fixed bed. Here the remaining carbon is almost completely gasified, ultimately at temperatures close to the ash fusion point. The incoming air and steam are preheated as they flow through the descending ash, thereby cooling the ash. Gas produced is withdrawn from gas outlets at two levels. A portion of the gas formed in the gasification zone is withdrawn from the bottom outlet and is called clear gas. The remainder of the gas from the gasification zone passes through the distillation and drying zone and then flows through the top outlet, (top gas). To produce a cold, clean gas suitable for feeding to desulfurization processes, the top gas flows to a tar precipitator. The detarred gas is then cooled and sent to an oil precipitator which removes oil and water droplets. Gas exiting the clear gas outlet flows to a cyclone where entrained dust is removed. It is then cooled in a heat exchanger and/or waste heat boiler being added to the cleaned top gas. The resulting product gas is then sent to a sulfur removal system to produce a low BTU gas. A medium BTU gas can be produced by substituting oxygen for air.

FEED REQUIREMENTS: Double screened coal, typical size ranges from +1/4" to 1"; +1/2" to 1 1/2". Gasifier will accept coals with a free-swelling index of less than 2 1/2".

OPERATING CONDITIONS: The temperature in the gasification zone is 2,200 degrees Fahrenheit at atmospheric pressure.

GAS PRODUCED:

		O_2 Blown	Air Blown
BTU/scf		280	175
Mole %	CO	37.5	28.3
	CO_2	18.0	4.5
	H_2	38.4	17.0
	CH_4	3.5	2.7
	H_2S + COS	0.4	0.3
	N_2 + Ar	2.2	47.2

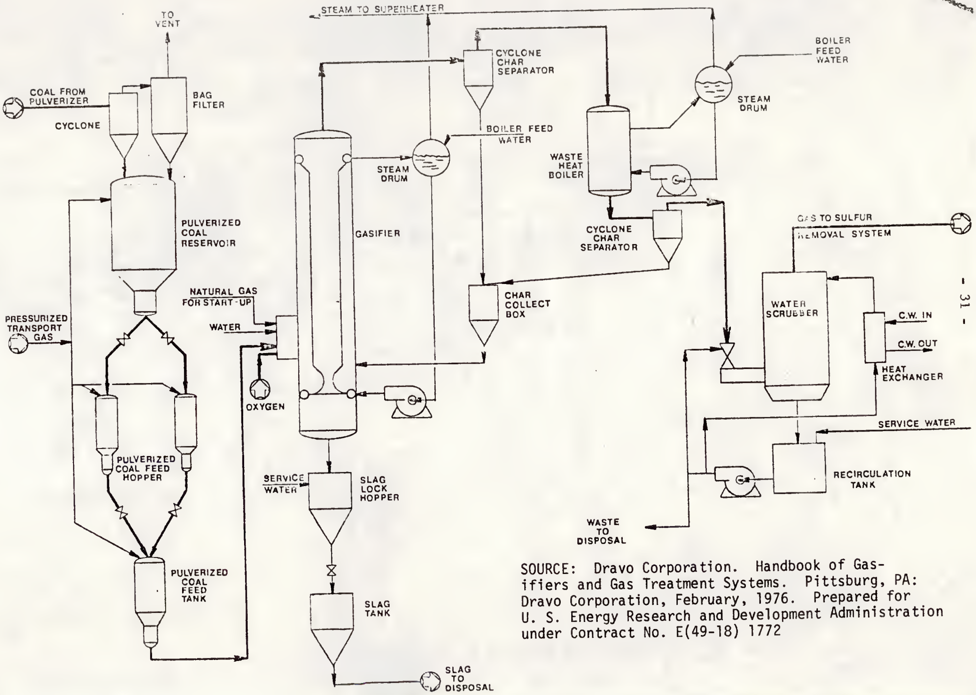
BY PRODUCTS: One hundred fifty pounds of oil per ton of input coal.

THERMAL EFFICIENCY: Cold gas efficiency -- 77 percent, overall thermal efficiency -- 88 percent, raw hot gas efficiency -- 92 percent.

Following are process flow diagrams for the previously described processes.

FIGURE 9

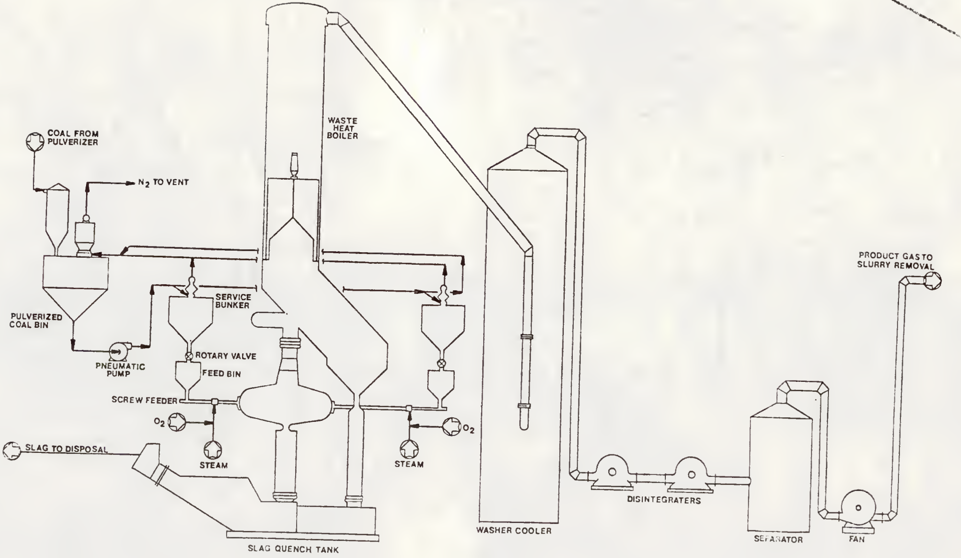
B & W COAL GASIFICATION SYSTEM



SOURCE: Dravo Corporation. Handbook of Gasifiers and Gas Treatment Systems. Pittsburg, PA: Dravo Corporation, February, 1976. Prepared for U. S. Energy Research and Development Administration under Contract No. E(49-18) 1772

FIGURE 10

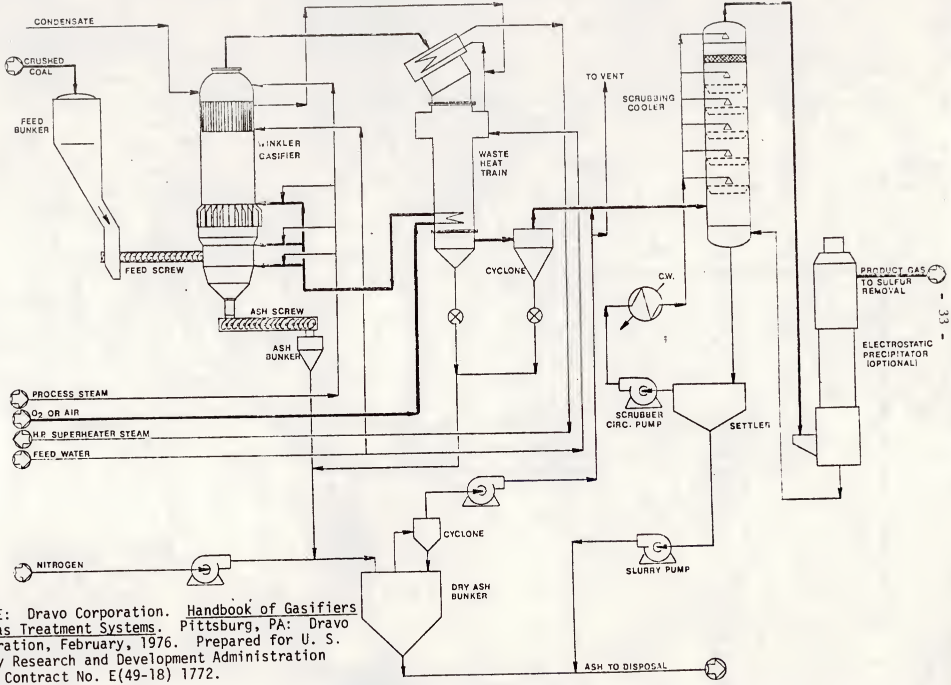
KOPPERS-TOTZEK COAL GASIFICATION SYSTEM



SOURCE: Dravo Corporation. Handbook of Gasifiers and Gas Treatment Systems. Pittsburg, PA: Dravo Corporation, February, 1976. Prepared for U. S. Energy Research and Development Administration under Contract No. E(49-18) 1772.

FIGURE 11

WINKLER COAL GASIFICATION PROCESS

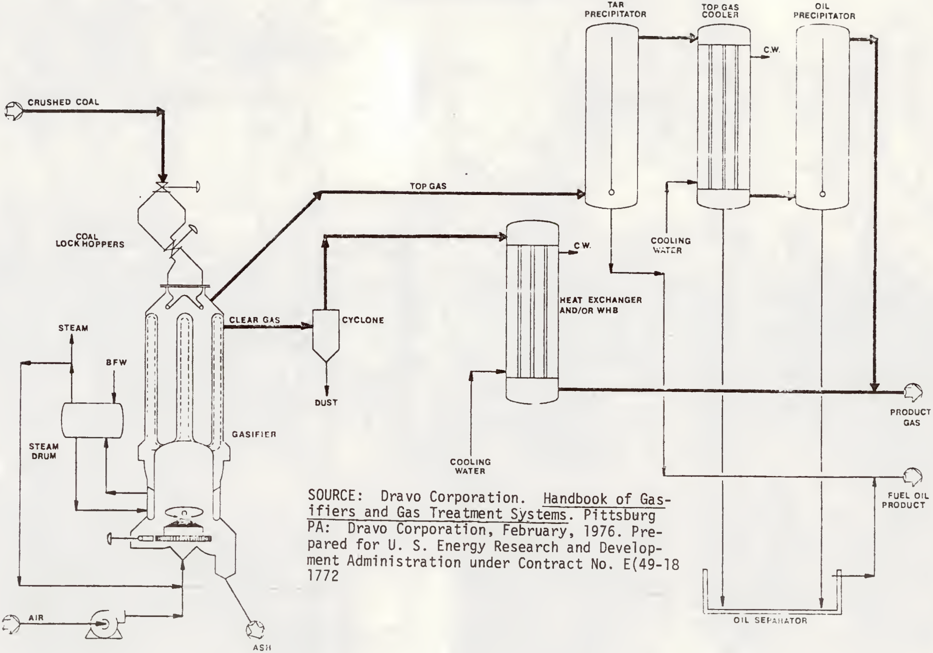


SOURCE: Dravo Corporation. Handbook of Gasifiers and Gas Treatment Systems. Pittsburg, PA: Dravo Corporation, February, 1976. Prepared for U. S. Energy Research and Development Administration under Contract No. E(49-18) 1772.

FIGURE 14

WD/GI COAL GASIFICATION SYSTEM

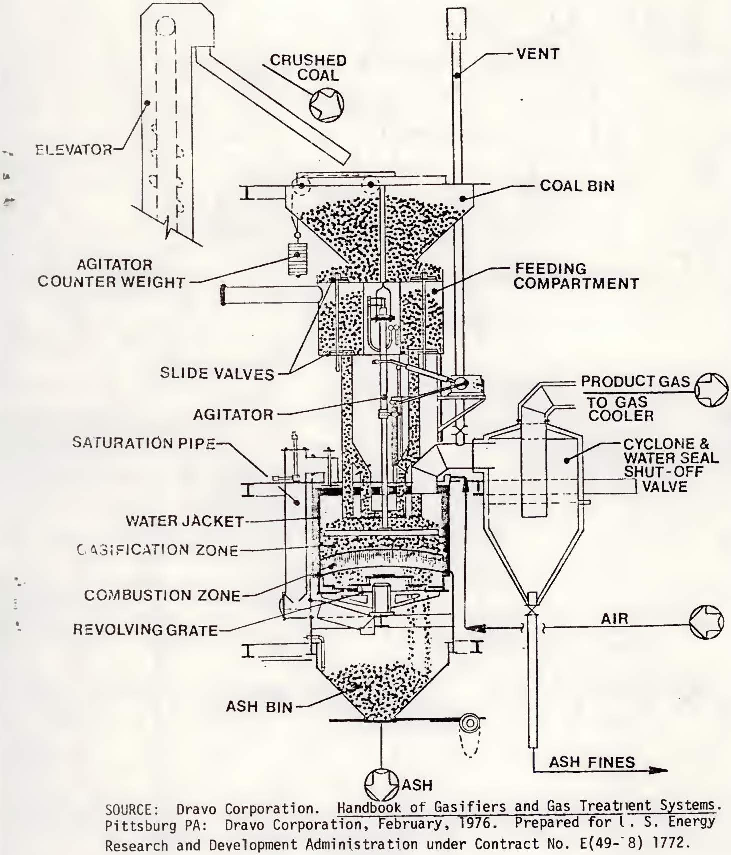
(TO PRODUCE COLD CLEAN GAS)



SOURCE: Dravo Corporation. Handbook of Gasifiers and Gas Treatment Systems. Pittsburg PA: Dravo Corporation, February, 1976. Prepared for U. S. Energy Research and Development Administration under Contract No. E(49-18 1772

FIGURE 13

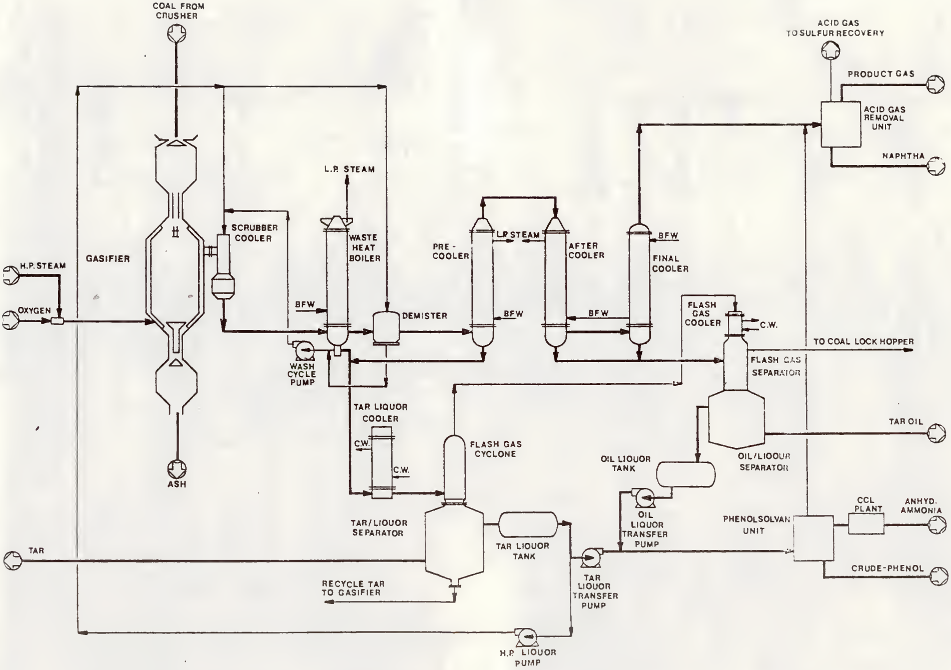
WELLMAN-GALUSHA AGITATED GASIFIER



SOURCE: Dravo Corporation. Handbook of Gasifiers and Gas Treatment Systems. Pittsburg PA: Dravo Corporation, February, 1976. Prepared for U. S. Energy Research and Development Administration under Contract No. E(49-18) 1772.

FIGURE 12

LURGI COAL GASIFICATION SYSTEM



SOURCE: Dravo Corporation. Handbook of Gasifiers and Gas Treatment Systems. Pittsburg PA: Dravo Corporation, February, 1976. Prepared for U. S. Energy Research and Development Administration under Contract No. E(49-18) 1772.

Personal communication between Andrew J. Grant, Woodall-Duckham (USA) Ltd., and Mr. William Christiansen, Lieutenant Governor, State of Montana, May 1976.

The Woodall-Duckham (W-D) two-stage coal gasification process first converts coal to a char or semi-coke which is then gasified conventionally. The process was developed on lignite and subbituminous coals; however, it also works on some bituminous coals. The process produces 200 BTU/scf gas at 92 percent efficiency. The cost of gas produced could be as low as $1.60/ million BTU without desulfurization. Plants range in size from 1 to 20 billion BTU/day. Capital costs range from $1 to $2 million per daily billion BTU, depending on plant size, degree of purification required, and supporting facilities needed.

Grant, A.J. and M.J. Hemingway. "Low and Medium BTU Gas and the WD/GI Process", Presented to the Institute of Gas Technology Symposium on Efficient Use of Fuels in the Metallurgical Industries, Chicago, Illinois, December 1974.

Most furnaces, boilers and other equipment need not be derated when burning Woodall-Duckham (W-D) low BTU gas. Papers published on derating assume gas calorific values in the range of 100 to 125 BTU/scf while the Woodall-Duckham process produces 200 BTU/scf gas. W-D gas produces about ten percent more products of combustion than natural gas. However, modifications or adjustments to burner systems will be necessary when changing from natural gas to any low BTU gas. When considering changes to burner equipment the installation of dual fuel (oil and gas) burners should be considered since W-D gasifiers produce about 13 percent of their thermal output as high quality fuel oil.

A standard W-D plant has an output of four billion BTU's per day for two gasifiers. Gas production costs for this size plant could range from $1.60 to 2.10 per million BTU's (1974 dollars) with utility financing and coal costed at $20/ton. Variables affecting gas cost include coal properties, particularly sulfur content. In view of steadily rising power costs, every effort should be made to avoid using oxygen for the production of industrial fuel gas.

Whiteacre, R.W., J. Frank Farnsworth, and D. Michael Mitsak. "The Koppers-Totzek Process and its Application to Industrial Needs", Presented to the "Clean Fuels from Coal" Symposium, Institute of Gas Technology, Chicago, Illinois, June 1976.

Eighty-six percent of the coal-based synthetic ammonia plants constructed since 1950 utilize the Koppers-Totzek (K-T) gasifier. This represents 5,195 tons of ammonia per day. The first commercial K-T gasifier was installed in Finland in 1952. The process does not produce tars, oils or phenols. Coal feed size is not important with the K-T gasifier; the entire mine output can be utilized. The K-T gasification process consists of four major steps: feed preparation, gasification, heat recovery and gas cleaning, and sulfur recovery. Carbon conversion is a function of the reactivity of the coal and approaches 100 percent for lignites. The heating value of the product gas is equal to 70 to 79 percent of the calorific value of the input coal. Combustion characteristics of K-T gas will permit its interchangability with natural gas as well as with other fuels. Existing burner units can burn gas of 300 BTU's/scf or higher with only minor alterations to the unit and without adverse effects on boiler efficiency. Below 300 BTU/scf boiler efficiency decreases rapidly. Figures 15 and 16 give data on the Koppers-Totzek gas chemical characteristics and costs.

FIGURE 15

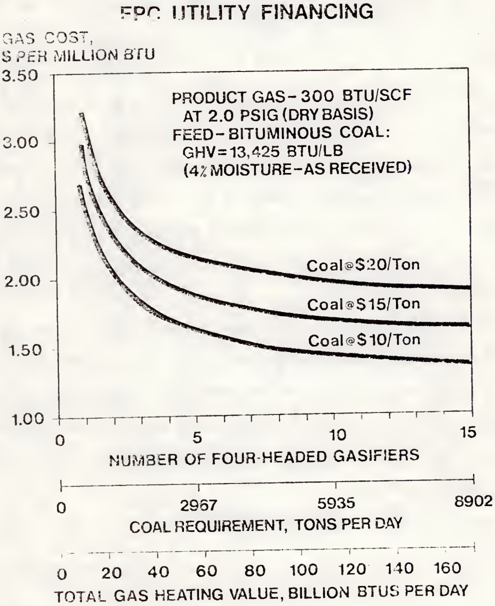
KOPPERS-TOTZEK GASIFIER DATA FOR VARIOUS FUELS

GASIFIER FEED	Lignite	Eastern Coal	Green Petroleum Coke
Dry Feed to Gasifier Analysis, Wt%			
C	58.2	76.2	88.0
H	4.3	5.0	4.5
N	1.1	1.3	1.4
S	1.5	0.7	4.3
O	14.2	6.6	1.0
Ash	12.7	8.2	0.2
Moisture	8.0	2.0	0.6
Total	100.0	100.0	100.0
Gross Heating Value of Dried Feed, Btu/Lb	10,050	13,705	15,690
Oxygen 98% Purity, Tons/Ton Dried Feed	0.731	0.916	0.950
Process Steam, Lb/Ton Dried Feed	281	885	1,182
GASIFIER OUTPUTS			
Jacket Steam, Lb/Ton Dried Feed	457	627	629
High Pressure Steam Lb/Ton Dried Feed @ 1500 psig/ 596°F (Saturated)	2,762	4,171	4,645
Raw Gas Analysis, Vol%, Dry			
CO	56.87	53.27	52.22
CO_2	10.00	10.00	10.00
H_2	31.30	35.43	35.40
N_2 + Argon	1.18	1.07	1.10
H_2S	0.60	0.22	1.20
COS	0.05	0.01	0.08
Total	100.00	100.00	100.00
Dry Gas Make — SCF/Ton Dried Feed	54,835	72,448	77,500
Gas Gross Heating Value, Btu/SCF, Dry	289	286	283
% Heating Value of Gas/Heating Value Feed (Gross Basis)	78.9	75.7	69.9

SOURCE: Whiteacre, R. W., J. Frank Farnsworth, and D. Micheal Mitsak. "The Koppers-Totzek Process and its Application to Industrial Needs", Presented to the "Clean Fuels from Coal" Symposium, Institute of Gas Technology, Chicago, Illinois, June 1976.

FIGURE 16

KOPPERS-TOTZEK GASIFICATION PROCESS AVERAGE GAS COST



BASES:

1. Feedstock: Bituminous Coal
2. Plant Life: 20 Years
3. Depreciation: Straight Line
4. Capital Structure: 75% Debt
   25% Equity
5. Interest Rate on Debt: 9%
6. Rate of Return on Equity: 15%
7. Federal Income Tax Rate: 48%

SOURCE: Whitearce, R. W., J. Frank Farnsworth, and D. Micheal Mitsak. "The Koppers-Totzek Process and its Application to Industrial Needs", Presented to the "Clean Fuels from Coal" Symposium, Institute of Gas Technology, Chicago, Illinois, June 1976.

Personal communication between David D. Woodruff, General Sales Manager, Engineering Group, McDowell Wellman Engineering Company, Cleveland, Ohio and William Christiansen, Lieutenant Governor, State of Montana, May 1976.

The Wellman-Galusha Company is currently producing gasifiers capable of generating 4.8 to 9.6 million cubic feet of synthetic gas per day. These gasifiers work on coke, charcoal and bituminous coal as well as anthracite. A good bituminous coal will produce 50 to 70 million BTU's/hr. in a 10 foot diameter gasifier as opposed to 25 to 40 million BTU's/hr. for anthracite coal. The clean gas efficiency of the process is 75 percent; the hot raw gas efficiency is 90 percent. Gas of 135 to 150 BTU/scf is produced. The McDowell-Wellman Company does not have extensive experience in the gasification of western coals; however, they believe that some of them will not gasify readily because they tend to disintegrate when exposed to heat. The ten foot diameter gasification unit with a cyclone dust collector is priced in the $250,000 range, F.B. Cleveland. Delivery is 15 to 18 months after the date of order.

Stokes, Charles A., Stokes Consulting Group, Princeton, N.J. "Gas from Coal Has Future as Boiler Fuel", Paper presented to Chemical Marketing and Economics Division, American Chemical Society, 172nd National Meeting, San Francisco, California, September 1976.

Industrial low BTU fuel gas will cost $3.50 per million BTU's ± 25 cents by 1980. After that, coal derived gas will probably become relatively cheaper compared to other sources of clean fuel. However, gas from coal will not become economic until natural gas is decontrolled. Use of natural gas in process heaters and boilers gives 60 to 80 percent efficiency and only 250 to 300 BTU/scf synthetic gas is required to avoid boiler and heater derating. For plants requiring five to 25 billion BTU's/day a two-stage gasifier such as the Woodall-Duckham is recommended. Using lignite at $10 per ton, this unit can produce gas for about $2.90 per million BTU, but the gas is only 170 BTU/scf. Oxygen blown operation costs $3.50/million BTU's.

For plants requiring 25 to 100 billion BTU's per day, a high velocity fluid bed process such as the Winkler is recommended. With oxygen at $30 per ton and western coal at $15 per ton delivered, this process produces gas at $3.50 per million BTU's. The Koppers-Totzek process can be used for very large gas requirements (100 to 250 billion BTU's/day). At this scale, gas from the Koppers-Totzek process will cost $3.20 to 3.80 per million BTU's.